A High Speed CCD Camera System

Michael Hoffberg

Chuande Liu

Camera Uses

Visible Light
X-Rays

Time Resolved Imaging
- X-Ray Crystallography
- Motion Analysis
- Air Flow
- Combustion Analysis
- Chemical Reaction Analysis
  (Atomic Scale)

Digital Imaging
- Medical Imaging
  - Faster Camera = Shorter Exposure
- Quality Control in Mass Production

Table 1: Conventional vs. High Speed CCD Cameras

Camera Characteristics	Conventional CCD Camera (TV)	High Speed CCD Camera
Number of Pixels	307,200 (640 x 480)	262,144 (512 x 512)
Frames per Second (fps)	30	up to 120
Pixels per Second (maximum)	10,000,000	30,000,000
Dynamic Range	7 - 8 bits	12 - 14 bits
Number of Discrete Levels	128 - 256	4096 - 16384
Data Rate	10 MB/second	60 MB/second

Advantages of the High Speed CCD Camera System

- The storage mechanism for the Camera System is digital, not analog video tape
- Dynamic range (number of digitized levels) is superior in the Camera System
- Scientific grade components are used in the Camera System
- Pixel size of the CCD used in the Camera System is larger
- The flexible Camera System can be easily reconfigured for different CCDs
- The Camera System can be used for both visible light and X-ray imaging

Advantages of the High Speed CCD Camera System

Data storage of a conventional analog TV camera is tape, an unstable medium that will degrade over time. The high speed CCD camera is a digital system that archives its data as discrete bits so that data degradation over time or usage is not a problem.

The number of discrete levels corresponds to the distinct brightness levels (shades) of a color that can be discerned. A fax machine can be thought of as a system that can distinguish between two levels, black and white. The quality of a reproduced picture increases as more shades are added to the available palette.

When the picture from a TV camera is digitized (converted to numbers) the picture quality is typically limited to a maximum of 256 shades of a color (gray), and more likely only 128 shades. This is due to two reasons, the quality of the camera that is used, and that commercial video systems were never designed to handle/display more than 256 levels.

The High Speed CCD Camera is a device built specifically for scientific research. The highest quality parts are used so that a superior image can be recorded.

Block Diagram

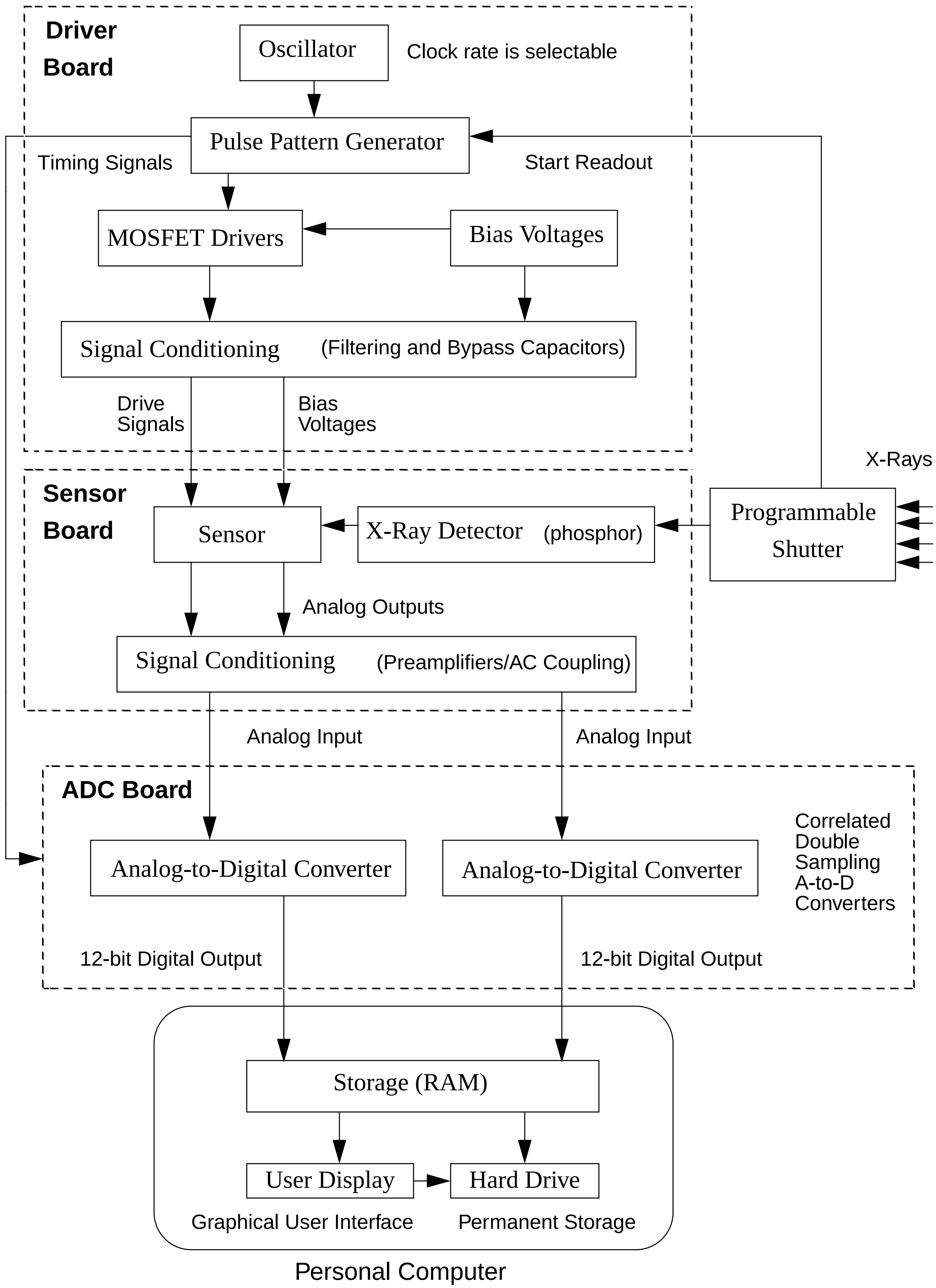


Table 2: Detector and Readout Rates

Device	Readout Options	Date
TH7895 512x512 with a 1:1 fiber optic window, two readout ports and 19 micron pix els, can be used with a 3:1 taper	Full frame: 100 frames/sec Single row: 50 usecs/row Storage mode: 0.5 usec/row	3/96
TC215 1024x1024 with 1:1 fiber optic window, two readout ports and 12 micron pix els, can be used with a 3:1 taper	Full frame: 20 frames/sec Single row: 50 usec/row Storage mode: 1.5 usec/row	5/96
TH7896 1024x1024 with 1:1 fiber optic window, four readout ports and 19 micron pix els, can be used with a 3:1 taper	Full frame: 30 frames/sec	12/96
4x4 pixel PAD	Full frame: 5 usec limit 8 frames	8/96
TC215 1024x1024 with 5:1 fiber optic windo w, image intensifier, readout as 512x512 device with 24 micron pixels	Full frame: 40 frames/sec Single row: 50 usec/row Storage mode: 3.0 usec/row	2/97
2x2 TC215 setup as four times the above de vice, here 4 CCDs are readout in parallel	Full frame: 40 frames/sec Single row: N/A Storage mode: 3.0 usec/row	5/97
100x100 pixel PAD	Full frame: 5 usec, limit 8 frames	6/97
Sarnoff 512x512, 16 outputs, Correlated Double Sampling on chip	Full frame: ~800 frames/sec	9/97

Camera System Description

The goal of our group is to produce high speed X-Ray detectors. The detector that will be described is a 2 dimensional detector using a CCD (charged-coupled device) as the sensing element.

Current video technology is geared toward the consumer market. Consumer video cameras will be simplified as having 640x480 pixel resolution, with each pixel having an 8-bit value. The frame rate of this camera is 30 frames per second, with each frame containing 2 interlaced fields (odd and even rows). These camera typically have one output, the pixel rate is about 10 Mega-pixel/second.

Companies that sell CCD cameras for scientific applications provide cameras with higher dynamic range per pixel (16-bit) or faster frame rate (up to 1000 frames/second), but none offer a combination of high dynamic range and speed.

The current camera that we have developed at the Experimental Facilities Division of the Advanced Photon Source has a 512x512 pixel resolution, 12-bit values for each pixel, and two outputs (TH7895). The maximum pixel rate from each output is over 15 Mpixel/second, giving a maximum frame rate of over 110 frames per second. The lab prototype of this camera can operate at this speed.

Unlike video based systems that are frame transfer and are not designed to be programmable, this camera system uses full frame transfer scientific chips designed for high-dynamic range and low noise applications with programmable readout speeds and integration times that can be configured to the application. This device can use both electronic and mechanical shuttering. Further the readout of the device is synchronized to an external mechanical shutter and can be synchronized trivially for any integration intervals.

The system consists of the CCD driver board (containing the voltage regulators, CCD MOSFET drivers, and the timing circuitry), the CCD board (containing the CCD, some passive wave shaping circuitry and preamplifiers for the output signal), the analog to digital converter board (containing 2 CCD analog processors and line driving circuitry), and a computer with an interface capable of handling data rates of 40 MBytes/second.

The CCD driver board is partly based upon application notes supplied with the CCD. The actual timing/phasing of the signals is generated by a programmable logic device.

The camera system is composed of a backplane that interconnects the driver, power supply, digitizing and CCD boards. The system was designed so that the CCD can be thermo-electrically cooled (TEC). To do this, the CCD must be put in a vacuum, this prevents water condensation from forming on the CCD or coldfinger.

Each CCD has unique requirements for its drive signals, but generally the output signals are of the same magnitude. The system was designed such that if a new CCD were to be evaluated, all that would have to be changed is the driver board, and the CCD board inside the chamber.

Another important part of this system is the computer interface. This involves a high-speed computer digital interface and custom software. This prototype camera uses a 24-bit interface that is meant for 3 8-bit data streams. Instead 2 12-bit data streams are supplied. The software is capable of decoding the 2 streams and tiling them so that on the host computer can display the picture. Alternatively, a 512 MB VXI memory module (connected to the host PC by a MXI-II bus) can be used to capture data.

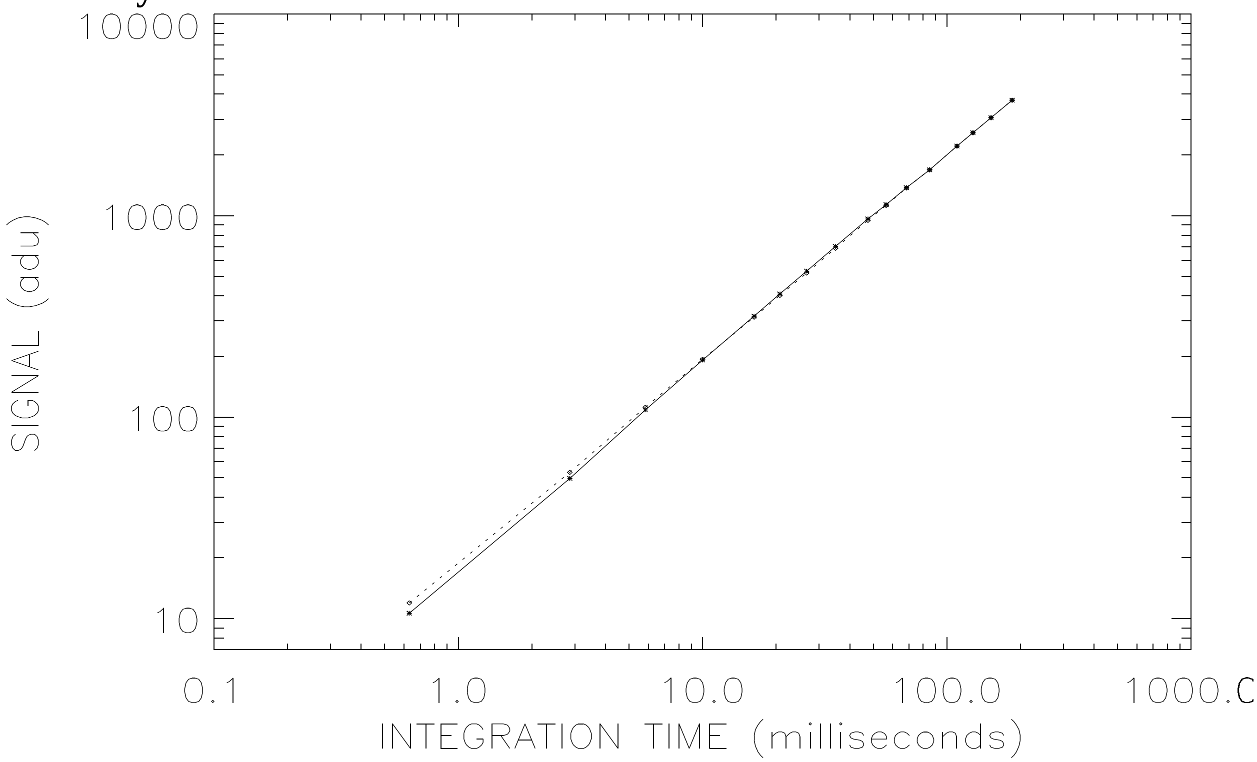
Features of the easy to use software include: - playing a live image (2 frames/second) - recording a specified number of frames in real time - single frame playback (forwards or backwards direction) - selection of an 8-bit window (within the 12 bits captured) which are to be displayed on the computer screen - single bit selection of which bit is to be displayed. In addition, rudimentary processing can be done on the data, such as row or column profile or a windowed histogram, mean or standard deviation can be displayed.

The software also allows the user to define an arbitrary rectangular area centered within the fame to be recorded, reducing the amount of information that is recorded and saved. After frames are recorded they can be saved to disk, The software and hardware runs on a Windows based PC with a PCI local bus slot. The software supports the Window's standard for Cut, Copy and Paste. The storage memory size (maximum number of frames) is limited by the amount of DRAM that the host computer system can contain.

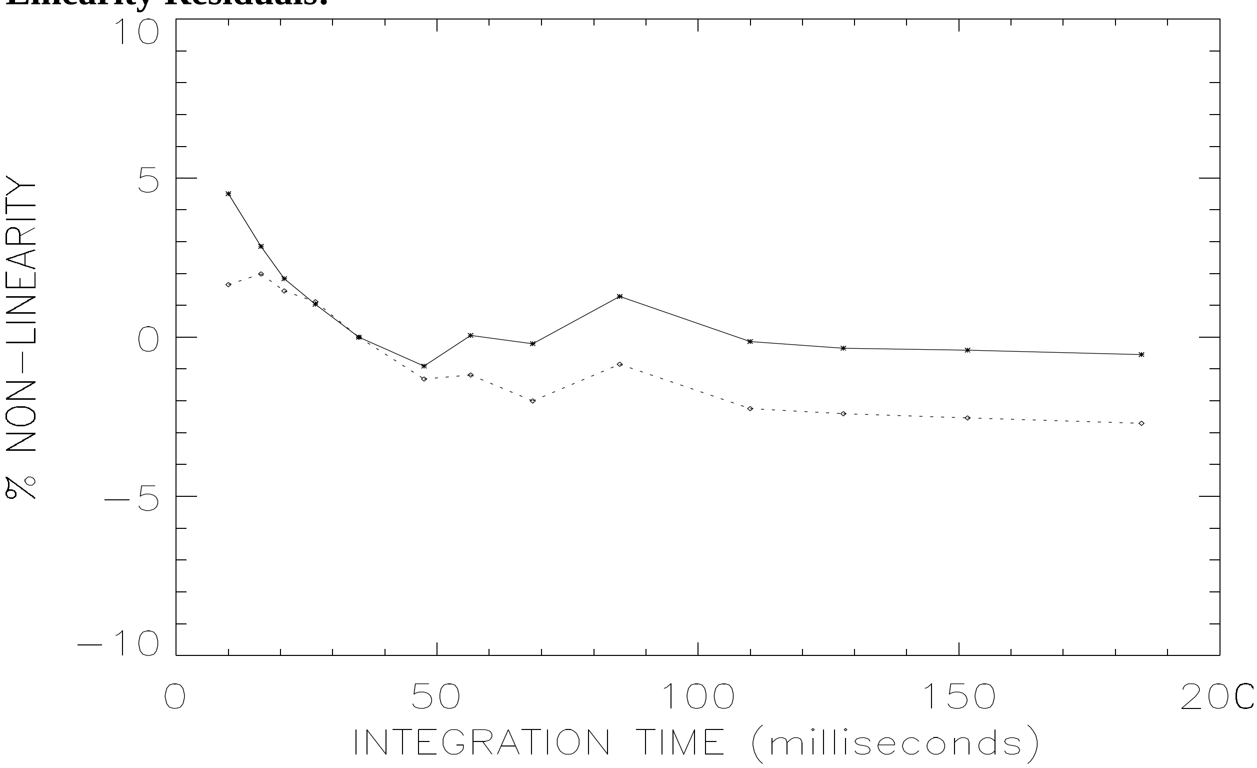
Characterization Results

Thomson TH7895, 2 output, 13.3 Mpixel/sec, 12-bit

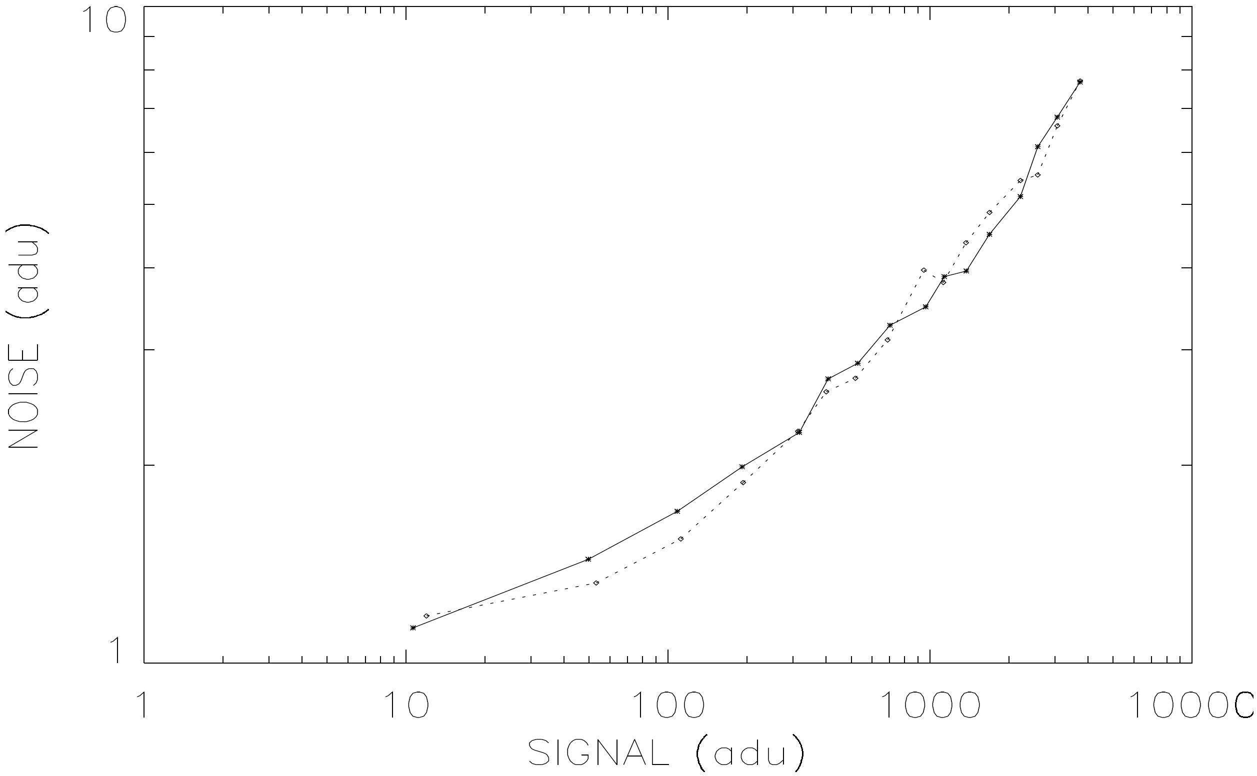
Linearity:



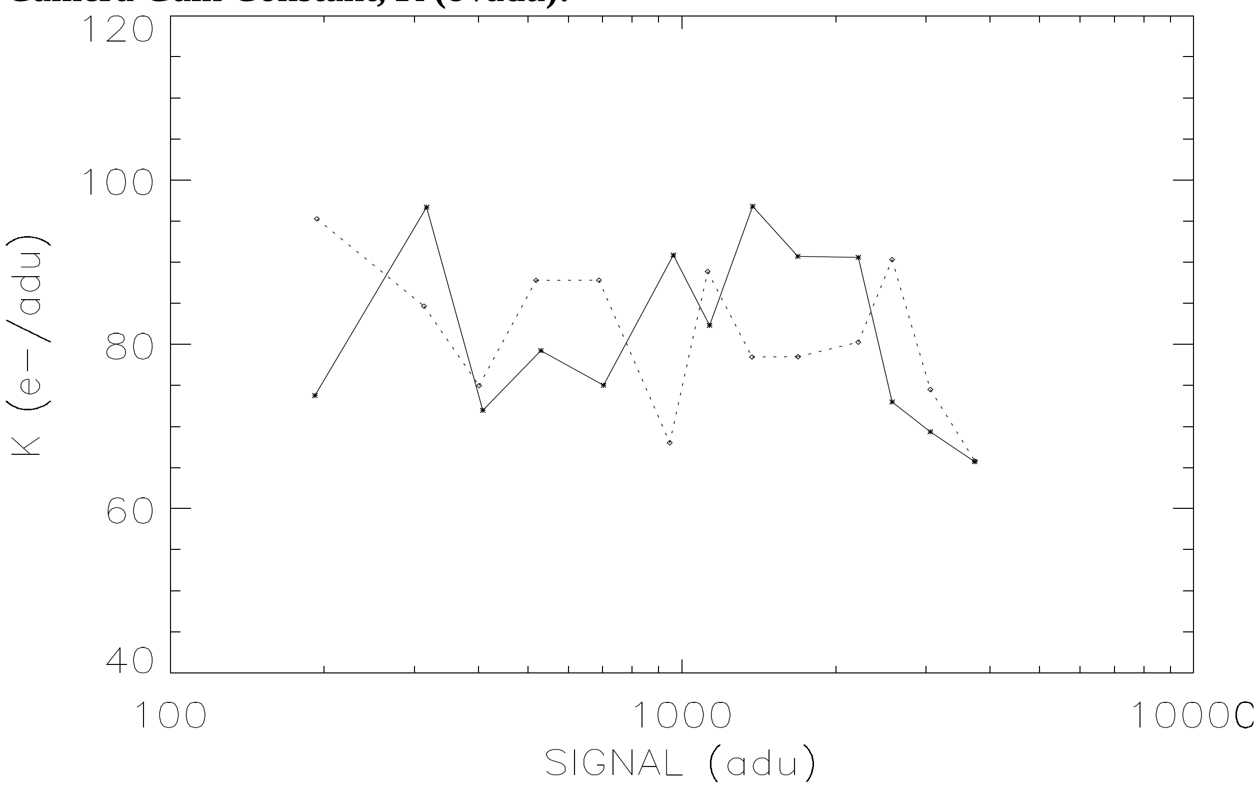
Linearity Residuals:



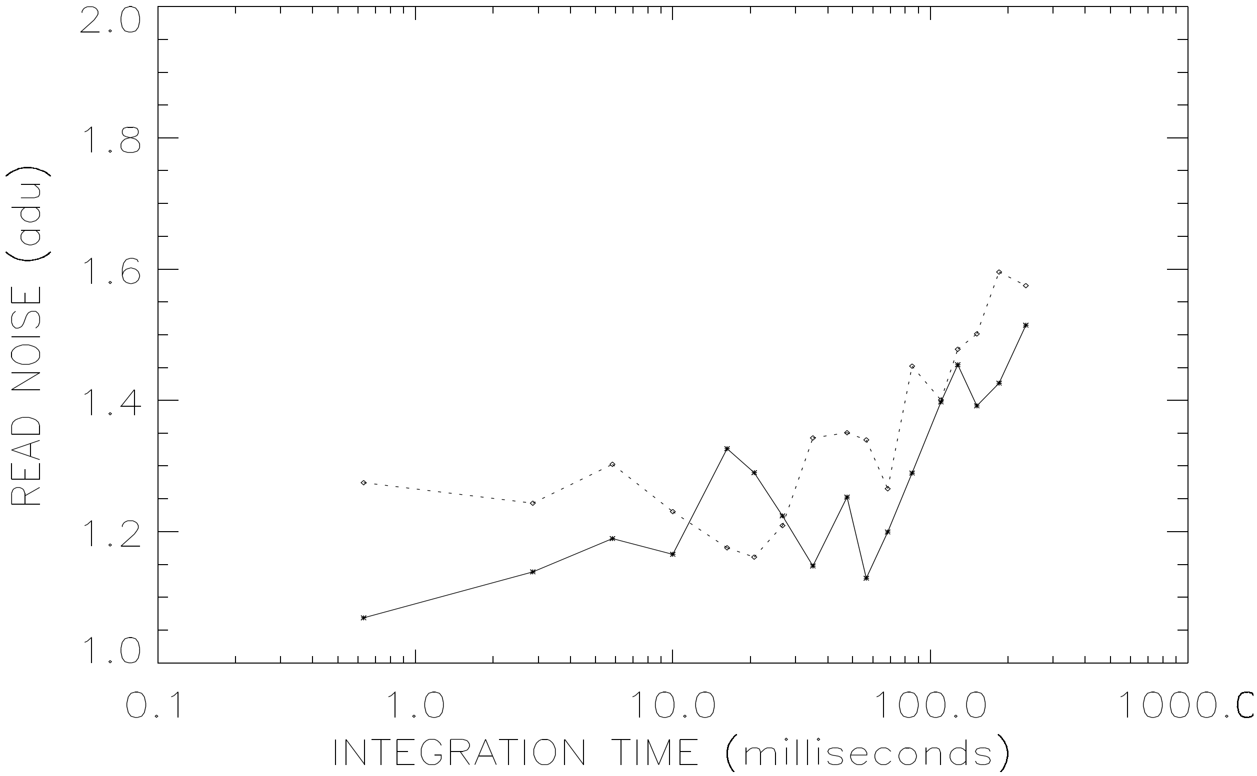
Photon Transfer Function:



Camera Gain Constant, K (e-/adu):



Read Noise:



Modulation Transfer Function: